ON CONDITIONS AFFECTING THE MAXIMAL RATE OF VOLUNTARY EXTENSOR AND FLEXOR MOVEMENTS OF THE RIGHT ARM.

By Robert Harvey Gault.

Introductory.

Experiments on the maximal rate of extensor and flexor movements of both arms in various classes of persons have been for some time in progress at the Laboratory of Psychology of the University of Pennsylvania. The results of this investigation, when published, will contribute material bearing on differences in maximal rate of movement for race, sex, for the right and left arms, and for extension and flexion. In the course of this enquiry several factors have appeared to exert a determining influence upon the rate of these movements. Not only are such general factors as practice and fatigue effective in modifying the rate but the position of the subject with reference to the instruments, his mental attitude toward the investigation, the stimulation which he receives from the directions of the experimenter, the direction of his attention to the various parts of the movement; all these and other factors from time to time are observed to affect the rate of movement of some or all subjects.

This monograph proposes to subject to the analysis of the experimental method certain of these factors that determine the maximal rate of voluntary movement. Its scope is restricted to an examination of certain conditions affecting the initial and preparatory stage of movements of maximal rate, *i. e.*, those in which the volitional element is at a maximum. For the purposes of this investigation I have employed extensor and flexor movements of the right arm.

It would be imposible within the limits of an inquiry of moderate proportions even to begin an examination of all the influences that probably have a share in the production of these movements. The factors with which I shall be concerned in this monograph are:

1. Various extents of running start;
2. The mean variations of the average rate of movement;
3. The back pressure or the backward start, *i. e.*, a pressure of variable amount exerted by the hand and arm against the post from which the movement is started;
4. The duration of the back pressure or backward start;

5. Various conditions such as practice, fatigue and the differential rate of extensor and flexor movements which have arisen incidentally in the course of the investigation.

The back pressure exerted barely enters the field of the subject's consciousness. The image of the end of voluntary movements is so vivid that the initial and preliminary stages cannot be successful rivals excepting by special effort on the part of the observer, and in this case the movement usually suffers either in speed or in accuracy or in both. But though these stages of movement are so dimly perceived the adjustments which take place within them are of no less interest to the psychologist who keeps a place in his scheme of psychology for reflex and automatic movements. It is doubtless due to the position which they occupy in the field of consciousness that they have received so little attention at the hands of psychologists and physiologists.

The studies of the initial stage of movement considered as the time of reaction, it is true, would fill volumes. But these studies usually do not include an examination of the relation between the reaction time and the movement which follows. On the other hand, the literature bearing upon the problem of this investigation is meagre. Camerer, in 1866 (2),[1] described as the "form" of a voluntary movement the characteristic successive variations in the rate of a horizontal movement of the arm from the beginning to the end of the course. The movement is at first slow, then increases, and finally decreases in rapidity. Camerer, however, did not employ movements of maximal rate. His results therefore do not bear directly upon the problem of the present investigation. They bring to light, nevertheless, at least one item of interest in this connection. Although the form of movement is approximately the same for extensor and flexor movements, the highest velocity in slow extensor movements is reached a little later in the course than the highest velocity in flexor movements. In other words, the running start, during which the arm is approaching its maximal velocity, is longer in extensor than in flexor movements. But nothing in the literature justifies the conclusion that the same difference would be found in movements of maximal rate.

The investigations of Loeb and Koranyi in 1890 (6) on horizontal movements of an arm lightly loaded, and those by Binet and Courtier in 1893 (1) on rapid writing movements appear to confirm Camerer's conclusion in a general way but add nothing of importance bearing on the problem of this investigation.

In 1892 Fullerton and Cattell (4:114 f.) made a brief report

[1] See References at the end of this paper.

of a few experiments on the maximal rate of movement. Their general procedure as well as the details of method are very nearly those which I have followed in my investigation. They employed similar extensor and flexor movements of the right and left arms, a course of the same extent, *i. e.*, 50 cm., and placed the subject in approximately the same position with reference to the apparatus which differed only in detail from mine. They report that the average time of a movement of the arm over 50 cm. in 10 separate series of 10 experiments each with, however, one subject only, varies from 96σ to 138σ. They believe this variation points to differences in the condition of the subject. In the same subject flexion of the right arm is found to be slower by 7σ than extension of the same arm. This contradicts the report of Charles Fere, in 1889 (3), to the effect that flexion of the upper limbs is not only more energetic but of greater velocity than extension. Fere admits, however, the possibility of occasional exceptions. As to the variations in the velocity of a single continuous movement of maximal rate from the beginning to the end of this course, Fullerton and Cattell are of the opinion that the rate is high at the beginning and diminishes toward the end of the movement.

The second problem of this investigation, to find the effect of the preliminary backward start or back pressure upon the subsequent movement, was first studied by Woodworth, in 1901 (9), who examined the extent of the upward movement of the clenched fist in its relation to a downward blow upon a table. He found that a forcible blow is not always accompanied by a great extent of preliminary upward movement. Although no constant relation appears between the force of the blow and the extent of the upward movement, by selecting a large number of the more forcible blows, he found that the average of the upward movements preceding them is greater than that of the upward movements accompanied by less forcible downward blows.

In an investigation of "antagonistic reactions" in 1903, W. G. Smith (8) discovered that about one-third of his subjects showed an unmistakable inclination to increase the downward pressure upon the key just before reacting. It is Smith's opinion that from the psychophysical point of view antagonistic reaction is due to the idea dominant in consciousness before the reaction being that of holding the finger pressed upon the key. When the signal for reaction comes it is quite conceivable that the first effect of the shock would be a more decided realization of the motor idea already in consciousness: *i. e.*, a more decided push upon the key. No attempt was made by Smith to find what relation, if any, exists between the antagonistic reaction and the subsequent movement.

In a study of reaction time and an outward rotatory movement of the arm, T. V. Moore (7:55 ff.), in 1904, found no constant relation between reaction time and movement time, and no evidence of an antagonistic reaction. It is probable, however, that he overlooked the latter for he says (7:13) that while waiting for the signal to react his subjects often "unwittingly" broke and re-made contact between the rotating arm of his instrument and the contact post.

The most recent study of the preliminary stage of movement is that of Judd, McAllister and Steele (5), published early in 1905. This is an investigation of the phenomena described by W. G. Smith. The experiments show that preparation for the final reaction movement by a gradual movement in the direction of reaction is, with most subjects, less favorable for a speedy reaction than the gradual antagonistic movement, (5:153.) On the other hand sudden antagonistic reactions are cases of excessive effort which is not always so applied as to be favorable to the speed of reaction. (5:171.) The result seems to justify their conclusion that a reaction is not a simple movement. Between the warning signal and the stimulus there is always a complex process of adjustment. (5:163.) The comparison of the effects of the gradual and the sudden antagonistic movement upon the final reaction appears to be the first contribution bearing upon one problem of my investigation, *i. e.*, the relation between the duration of the antagonistic phenomenon and the subsequent movements.

Apparatus and Method.

This investigation permits of the treatment of my experiments in two main divisions: first, those experiments which had to do with the effect of various extents of running start upon the rate of movement; and next in order, those dealing with the back pressure. My apparatus and methods differed somewhat in these two groups of experiments. In both groups, however, the time of the movement was recorded by the Hipp chronoscope controlled to a constant and variable error of less than one sigma by means of the Cattell drop screen. During the course of the investigation from the middle of October, 1904, to the end of February, 1905, 93 control series of 10 trials each were made. The variations of the averages of these 10 consecutive trials from the standard control time of the Cattell screen vary between 0.4σ and 1.3σ, the average constant error being 0.5σ. The mean variations range from 0.27σ to 0.89σ, the average mean variation being 0.56σ.

For the first group of experiments, namely, those dealing with the effect of the running start upon the rate of movement, we required a device to mark the beginning and the end of the

recorded part of the movement. For this purpose I used two instruments, one of which served as the starting-post of the movement and will be called the "starting contact," the other usually served as the finishing-post and will be called the "finish-contact."

In my experiments *without a running start*, the starting contact (See Fig. 1, A.) is adjusted to close the chronoscopic cir-

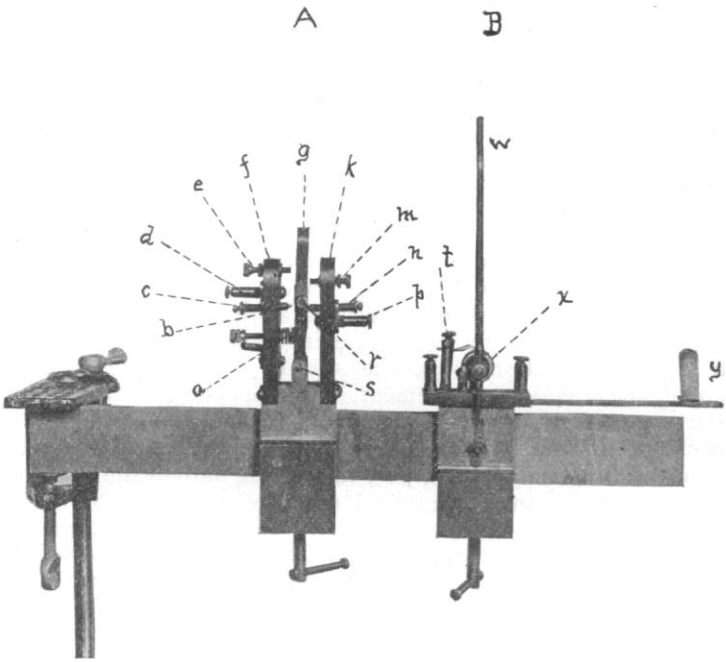

FIG. I.

A STARTING CONTACT.

a coiled spring.
b plunger pin of contact set screw.
c contact set screw.
d binding post for contact set screw.
e set screw acting as back-stop for starting-post.
f left upright of frame.
g starting-post movable about axis "*s*."
k right upright of frame.
m set screw acting as back-stop for starting-post.
n contact set screw.
p binding post for contact set screw.
r binding post for contact plate on starting-post.

B FINISH CONTACT.

t binding post.
w hickory stick, "finish post."
x ebonite contact disc.
y spring catch.

cuit at the beginning of a movement. When in use the instrument is fastened to the edge of a laboratory table or, as in my experiments, to a horizontal wooden bar, by means of a clamp which forms the lower part of the contact piece. The part of the instrument which extends above the level of the bar when it is clamped in position, as in Fig. 1, A, consists essentially of two wooden uprights, "*f*" and "*k*," fastened securely to the base. Between these and projecting above them is a light bar of ebonite "*g*," 9 x 2 x 0.5 cm. which I shall call the "starting-post." This post is movable through an arc limited by the distance, 2.5 cm., between the two uprights. By means of a set screw projecting from each upright, *e. g.*, "*e*" and "*n*" for movements to the right of the starting-post, the movement of the post may be restricted to any desired extent. In my experiments the set screws were adjusted to permit of a movement of the starting-post of 1 mm. at the level of the lower set screw "*n*," at which point the electrical contact was made. In practice the subject placed the first finger of the right hand, the back of the hand being uppermost, against the movable starting-post and held it in position against the set screw "*e*" of the upright on the left of the instrument. The hand was held in this position while the subject awaited the signal to make the required movement. The pressing back of the starting-post against the set screw is accomplished against the resistance of the adjustable spring "*a*." When the hand is removed from the starting-post the spring shoves the post vigorously forward over the small distance permitted by the set screw "*n*." This set screw carries at its inner extremity a plunger contact pin of platinum. The plunger pin "*b*" of the opposite set screw "*c*" is clearly visible in the illustration. That of the set screw "*n*" is thrust back into the body of the set screw by the pressure of the starting-post. On the face of the starting-post just opposite the contact set screw is a thin plate of platinum connected with the binding post "*r*." The circuit is closed by the plunger pin in the set screw "*n*" impinging upon the surface of this platinum plate.

This "starting-contact" is a double one. The upper set screw "*m*" of the upright on the right of the instrument, "*k*," may be brought into function with the set screw "*c*" and plunger pin "*b*" of the binding post "*d*." The starting-post carries on its left surface a second platinum plate which is insulated from that described above on the right surface, and is connected with a binding post on the reverse edge of the starting-post as seen in Fig. 1 A. The spring "*d*" may be adjusted to exert a pull to the left upon the "starting-post" instead of pushing it to the right as in the arrangement described above. Thus by changing the upper set screws and by adjusting the

spring, this "starting-contact" may be used to record a movement either toward the right from the starting-post or toward the left. In my experiments the apparatus was adjusted only as described in the first instance: to record movements toward the right. When movements in flexion were to be recorded, which naturally required a movement toward the left from the starting point, the subject stood back of the instrument, as represented in Fig. 1 A, thus placing the starting-post on his right and enabling him to move from it toward the left.

The finish contact (Fig. 1 B), employed to break the circuit at the end of such part of the movement as it was desired to record, consists essentially of a slender hickory stick "*w*," 15 cm. long, rotating about a horizontal axis which carries, in addition to the stick, which we shall call the "finish-post," a contact disc of ebonite "*x*," which may be so adjusted with reference to a platinum brush connected with the binding post "*t*," that the slightest movement of the finish-post from any given position will break, or, if desired, close an electric circuit. When used as a finish-post the contacts are so adjusted that the circuit is closed when the post is vertical. A slight movement of the post to the right will then break the circuit. As the post is often violently knocked down the instrument is provided with a spring catch "*y*," to prevent any possible rebound from closing the circuit after it has once been broken. The instrument shown in the illustration is more complicated than was necessary for my experiments. The horizontal axis is provided with a second disc similar to "*x*" so that two circuits may be controlled by the same movement of the post.

These two instruments were clamped to a horizontal bar at such distance apart that the stretch between the "starting-post" and the "finish-post" exactly equalled 50 cm. plus the thickness of the subject's right index finger. In extensor movements, the subject faced the instruments as represented in Fig. 1, with the centre of his body about ¼ of the length of the entire stretch from the starting-post to the finish-post. In flexor movements the subject faced the back of the instruments, as shown in Fig. 1, placing himself about ¾ of the distance of the entire stretch from the starting-post to the finish-post. When these instruments are clamped to the edge of a table around which it is not convenient for the subject to move, the finish-post shown in Fig. 1 B, is used to the right of the starting-post and another finish-post is clamped at the desired distance to the left, the latter instrument being appropriately modified for use in movements toward the left.

This set of three contact pieces was designed by Professor Witmer for the Laboratory of Psychology as an improvement on the rate of movement apparatus described by Fullerton and

Cattell. The Cattell instrument is cumbersome and difficult to set up outside of the laboratory. The Witmer set is easily transported, may be set up wherever a table can be found, and when once adjusted permits of movements of the right and left hand in both flexion and extension from nearly the same position.

In experiments *with a running start*, the starting-post described above and the finish-post were clamped upon the bar at a distance equal to the movement desired to be measured plus the running start intended to be allowed, which varied in my experiments from 0.25 cm. to 7.5 cm. At a distance from the starting-post equal to the running start, another instrument similar to that described as the finish-post was clamped to the horizontal bar. But in this case, the contacts on the horizontal axis were so adjusted that the circuit was open when the post was vertical, but closed upon the smallest movement of the post to the right. The circuit maker of the starting-post "*g*" Fig. 1, was thrown out of function and the subject started his movement from the starting-post as described above. At the signal he moved his hand as rapidly as possible to the finish-post, striking on the way the post inserted at the beginning of the stretch over which the time of movement is to be recorded.

For the second group of experiments, namely, those dealing with the effect of the preliminary backward start or "back pressure" upon the rate of movement, the apparatus, consisting of several instruments, was adapted to perform the following functions: (1) to close the chronoscope circuit at the beginning of the movement; (2) to break the chronoscope circuit at the end of the part of a movement intended to be recorded; (3) to measure the amount of "back pressure" at the start of this recorded movement in terms of grams or some other convenient unit; and (4) to measure the duration of this pressure. One of these instruments is illustrated in Fig. 2 and appears schematically also in the diagram, Fig. 3. The frame-work of the instrument (see Fig. 2), which is made of hardwood, consists of a baseboard "*A B*," 1 M. x 18 cm. x 2.5 cm., at one end of which is erected an upright support "*E*," 40 x 18 x 1.5 cm. From the upper extremity of this upright projects a horizontal arm "*D*," 18 x 3 x 2.5 cm., from which hangs a lever "*C*," 50 x 2.7 x 1 cm., suspended from a pivot pin "*h*" about which as an axis the lever is free to move in a vertical plane. This movement, however, is limited by a slot in the baseboard, 17 cm. long, through which the lever projects to a distance of 10 cm. below. This lever carries a make and break contact operated by a thin spring tongue of sheet copper 9 x 1 cm. against which the subject presses the index finger of the hand at the point "*g*." The upper end of this tongue is held tight

against the lever by the screw of the binding post "*k*." The excursion of the lower end of this spring tongue is limited by a yoke, "*f*," of sheet copper which is fastened to the lever by the binding post "*p*." The tongue of copper is adjusted to bear against the yoke so as to close the chronoscope circuit passing through the binding posts "*k*" and "*p*." When the subject presses against the starting lever the spring tongue is pushed back through a distance of 1 mm. against the surface of the lever.

For my experiments on the duration of the back pressure I needed also to record the time during which the subject exerted pressure upon the starting lever. For this purpose I employed another circuit passing to the spring tongue through the binding post "*k*" and from the spring tongue to the binding post

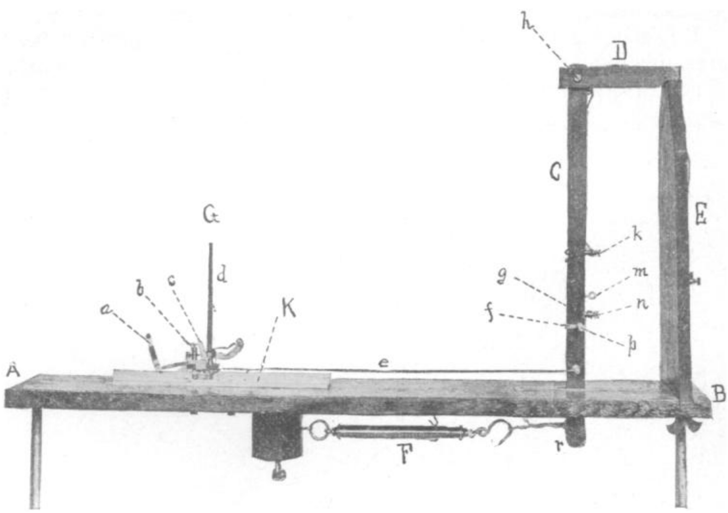

FIG. II.

A B baseboard.
C lever.
D horizontal arm supporting the lever C.
E upright support for arm D.
F spring balance.
G finish contact.
K track supporting finish contact G.

a spring catch for post d.
b binding post.
c brush.
d finish post.
e cord connecting lever C with finish contact G.
f yoke on starting contact.
g spring tongue of starting contact.
h pivot pin of lever C.
k binding post on spring tongue of starting contact.
m attachment for cord to marker W. Fig. 3.
n binding post for electro-magnetic marker circuit.
p binding post on contact yoke.

"*n*," which passes through the lever and offers a bearing on the surface next to the spring tongue.

The finish post "*d*" of the finish contact "*G*," a slender stick 15 cm. long, operates as does the "finish-post" "*w*" on the finish contact illustrated in Fig. 1, B. This post "*d*" is fixed to an axis bearing a contact disc rotating about the axis when the post is moved to or from its vertical position. This disc is so adjusted that a slight movement of the post "*d*" to the left from the vertical position breaks an electrical contact with the brush "*c*" projecting from the binding post "*b*." A spring catch "*a*" prevents the rebound of the post "*d*" after it has been forcibly knocked down. When the starting and finish contacts just described are placed in circuit with the chronoscope we have a rate of movement apparatus analogous to that illustrated in Fig. 1.

The measurement of the amount of backward start or back pressure is accomplished through the following special features of the instrument. The lever "*C*" extends through a slot in the baseboard and is attached below at "*r*" to a spring balance

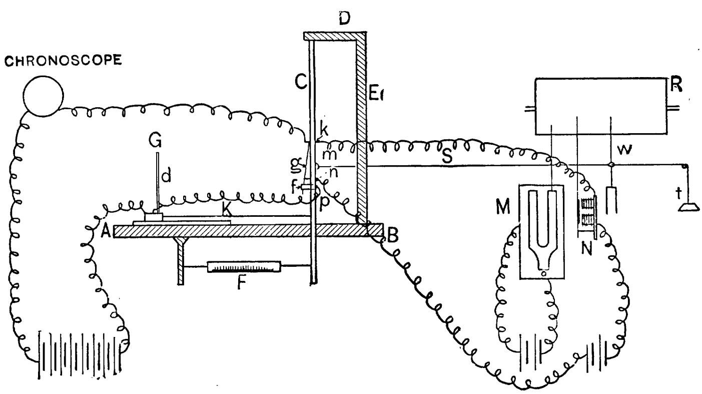

FIG. III.

A B baseboard.
C lever.
D horizontal arm supporting the lever C.
E upright support for arm D.
F spring balance.
G finish contact.
N electro-magnetic marker.
R kymograph.

d finish post.
f yoke on starting contact.
g spring tongue of starting contact.
k binding post on spring tongue of starting contact.
m attachment for cord to marker "w."
n binding post for electro-magnetic marker circuit.
p binding post on contact yoke.
s cord connecting lever C with marker "w."
t counterweight.
w kymograph marker.

"*F*" which is graduated in grams. From the scale of this balance, an observer can read in grams the amount of pressure exerted by the subject toward the right upon the lever "*C*." From this reading, the pressure exerted by the subject may be calculated by using the formula for a lever of the third order, the ratio of the arms being 1:1.5 when the subject's finger is held at "*g*." In practice, however, I did not obtain the "back pressure" readings directly from the spring balance "*F*," A light cord, "*s*" (see diagram Fig. 3) fastened to the lever "*C*" at "*m*" and passing through a slot in the perpendicular "*E*," was run through a pulley and held taut by means of a light weight. To this cord was attached a marker "*w*," by means of which any displacement of the lever "*C*" due to pressure exerted upon it toward the right, could be graphically recorded upon the smoked surface of the kymograph "*R*." By a simple computation, which will be set forth in the treatment of results, the operator can determine at the close of each series just how much "back pressure" is represented by each displacement of the marker recorded upon the kymograph sheet.

To keep the distance constant between the starting lever and the "finish-post" "*d*" despite variations in the displacement of the lever, a cord "*e*" ties the finish contact "*G*" securely to the lever "*C*." When the lever "*C*" is displaced toward the right, the "finish-post" is drawn after it upon the track "*K*" upon which it lightly rests. To reset the apparatus for a new experiment, the post "*d*" must not only be replaced in vertical position after each movement, but the finish contact "*G*" to which it is attached must be slid back upon the track "*K*" until the cord "*e*" is taut. A light brass rod was employed for this purpose at first, but was supplanted by the cord, owing to the friction of the rod on its bearings.

The duration of the back pressure was measured in hundredths of a second from the direct tracing of a 100 V. Koenig fork. The higher rate of speed at which the kymograph was necessarily run to obtain this tracing drew out the curve of back pressure made by the marker "*w*" to such an extent as to obscure the point at which the curve fell away from the horizontal, when back pressure on the lever "*C*" was released. The point at which the curve rose from the horizontal when the lever "*C*" was displaced remained readily distinguishable. I therefore used this point of the curve traced by the marker "*w*" to indicate the moment at which the back pressure began. To indicate the moment at which the back pressure ceased to act upon the lever "*C*" I employed the marker "*N*," Fig. 3. This marker made its tracing upon the kymograph in the same straight line with the points of marker "*w*" and the marker of

the tuning fork. The marker "*w*" was in a circuit connected with the binding posts "*k*" and "*n*," Figs. 2 and 3. The binding post "*k*" is connected with the metal tongue against which the subject presses his finger. The post "*n*" is a thumb screw with a platinized point projecting through the lever "*C*." When the subject presses his hand upon the metal tongue at the point "*g*," and thereby breaks the chronoscope circuit at the yoke "*f*," he presses the copper tongue against the platinized point of the thumb screw contact "*n*" thus closing the circuit through the marker "*N*." The release of back pressure upon the lever "*C*" is followed by (1) a movement of the metal tongue to the left thus breaking the circuit of the marker, and (2) a simultaneous movement in the same direction of the lever "*C*" communicated through the cord "*s*" to marker "*w*." I therefore expressed the duration of back pressure in terms of the number of vibrations of the tuning fork "*M*" occurring between the initial displacement from the horizontal of the line traced by "*w*" and the break in the line traced by "*N*" upon the release of the pressure of the spring tongue of the contact.

The same general procedure was employed throughout the experiments. At a given signal the subject placed the index finger of his right hand, back uppermost, against the starting-post, and, holding himself in readiness to make a movement of the hand at maximal rate toward the finish-post, awaited the signal to move. When this signal was given he knocked over the finish-post with as rapid a movement of the hand as possible. The subject is made to understand, however, that he may delay the start of the movement until he finds himself ready for a maximal effort. Details of the method will be introduced in connection with the treatment of results. It is obvious that the only way to guarantee a perfectly horizontal movement from the starting to the finish-post is to employ some device for guiding the hand. This would probably introduce so much constraint on the part of the subject that it was thought better to allow a perfectly free movement and to neglect the slight errors in time arising from this small variation in the extent or direction of movement.

Results.

The results of this investigation fall into two main divisions corresponding to the two groups of experiments mentioned above. They show, first, the effect of the running starts of various extent, and second, the effect of preparatory back pressure and its duration, upon the maximal rate of movement.

Experiments upon seven subjects furnished the data for the first group of results. One of these subjects, always designated in the tables by B., is a young woman, an undergraduate

student in biology. The others are men, and all are graduate students in psychology with the exception of T., who is an instructor in psychology. Only the last named subject had any experience in experiments on the rate of movement before this investigation was begun.

In the experiments which constitute the first group of my results, the subjects invariably made a series of twenty successive extensor movements, followed after a brief period of rest by a series of the same number of flexor movements. By alternating the series of extensor and flexor movements the effects of practice and fatigue may be expected to be distributed evenly over the results of both flexion and extension, thus rendering possible a satisfactory comparison of extensor and flexor times. The interval between the movements in a series was no greater than was necessary to allow the operator at the chronoscope to record the reading. During this interval the subject reset the instrument for the next experiment by raising the "finish-post" or "finish-posts," to the vertical position; in the second main group of experiments he also shoved the finish contact (see Fig. 2), back on its track "*K*" until the cord "*e*" was taut. Not more than ten series of twenty experiments each, in all 200 movements, divided equally between flexion and extension, were made by the same subject in one day. Usually a day's work was restricted to eight series. The average and mean variation of each series of extensor and flexor movements were computed and these formed the basis for the collation of the results presented in Table I.

The set of experiments which came first in chronological order was composed of a series without a running start. Three subjects, S., H., and B., made 800 extensor movements each, or forty series, and the same number of flexor movements. Two subjects, T. and M., who entered somewhat later into the investigation, made 160 extensor movements or eight series of experiments, and the same number of flexor movements.

The values which are reported in the lines opposite the letter which stands for each of these five subjects (see Table I) are the grand averages of the averages of the separate series. I give in this table in vertical column below the caption "Subj." the letters which represent the names of the five subjects. In the second column under the caption "Movt." I indicate by "Ex." or "Flex." whether the line contains values of extensor or flexor movements. In the third column headed "o." I give for each subject the grand average of the extensor and flexor experiments comprising what I have called the first set, namely, those made without running start. At the bottom of the table I give the combined averages of the extensor and flexor movements of the five subjects, and also, for a special

purpose which I shall have occasion to refer to shortly, the averages of the three subjects only, S., H., and B.

By referring to the table it will be seen that the extensor movement is performed by my five subjects, on the average, in 116.1σ and the flexor movement in 102.4σ, a decisive advantage in favor of the flexor movement of 13.7σ. An inspection of the individual values will show that the five subjects differ greatly among themselves in average rate of speed. The most rapid are S. and T. who are tall and possessed of long arms. Next in order

TABLE I.

		Time.					Mean Variation.					Excess of Ex. over Flex.				
Subj.	Mov't	0	0.5	1	3	7.5	0	0.5	1	3	7.5	0	0.5	1	3	7.5
S.	Ex.	83.2	71.5	69.8	81.6	67.1	5.09	3.3	3.9	2.9	2.6	4.9	5.2	9.7	10.9	9.3
	Flex.	78.3	63.8	60.1	70.7	57.8	5.6	2.3	3.6	2.9	1.7					
H.	Ex.	122.6	89.7	83.9	80.7	91.4	8.5	5.2	4.1	5.0	4.7	18.2	-9.8	4.7	-5.4	2.2
	Flex.	104.4	99.5	79.2	86.1	89.2	10.1	4.7	5.2	4.2	4.9					
B.	Ex.	155.7	112.2	109.3	99.1	99.7	12.1	4.9	5.0	3.6	5.3	25.2	21.5	15.6	18.0	14.2
	Flex.	130.5	90.7	93.7	81.1	85.5	12.0	4.4	4.9	3.2	5.6					
T.	Ex.	94.7		81.2	73.8	72.5	4.8		2.8	3.1	2.3	8.5		8.8	13.7	10.9
	Flex.	86.2		70.5	60.1	61.7	7.1		3.4	2.3	1.1					
M.	Ex.	124.3	118.3	98.7	94.2	114.6	14.5	3.4	3.1	2.2	5.3	11.5	9.2	11.5	19.1	24.9
	Flex.	112.8	98.4	87.2	75.2	89.7	18.3	4.8	4.6	3.4	5.6					
Total Avs.	Ex.	116.1	97.9	88.6	85.8	89.0	8.9	4.2	3.8	3.4	4.0	13.7	9.8	10.5	11.2	12.2
	Flex.	102.4	88.1	78.1	74.6	76.8	10.6	4.0	4.3	3.2	3.8					
Avs. of S. H. B.	Ex.	120.5	91.1	87.6	87.1	86.1	8.6	4.5	4.3	3.8	4.2	16.1	5.6	10.0	7.8	8.6
	Flex.	104.4	84.6	77.6	79.3	77.5	9.2	3.8	4.5	3.4	4.0					

Average times in sigma and average mean variations of extensor and flexor movements over 50 cm. without a running start, and with four extents of running start. For the number of experiments of which these are the collated averages see text, page 369. The table gives also the excess of extensor over flexor values.

are H. and M. who are both men with short arms, while B., who has the longest times, is a woman of somewhat less than medium stature. These differences between the subjects apply with respect to both extension and flexion, that is, a subject who is relatively more rapid in extension is also more rapid in flexion. The differences in favor of flexion which may be found in the column headed "o." in the third group of columns, under the caption "Excess of Ext. over Flex." vary from a minimum of 4.9σ with the most rapid mover to 25.2σ with the slowest mover.

The average mean variations of the series of experiments in this set is found in the first column headed "o." of the group

of columns under the heading "Mean Variation." The average mean variation of the five subjects is 8.9σ for extension and 10.6σ for flexion. Thus the mean variation for flexion is greater than the mean variation for extension despite the fact that the average value of an extensor movement is greater than the average value of a flexor movement. This difference between the average mean variation holds true for all the subjects with the exception of B. whose average mean variations favor flexion by 0.1σ. This subject has the longest average values for the movements. It would appear from this result that flexion may be more rapidly executed than extension but a maximal rate is less constantly maintained.

The second set of experiments in chronogical order are made with a start of 3 cm., the third with a start of 7.5 cm., the fourth with a start of 0.5 cm., and the fifth with a start of 1 cm. Each subject, excepting T. and M., made 520 extensor and the same number of flexor movements or 26 series of each movement. T. and M. made but 8 series. From these results I obtained the average values and the mean variations set down in the columns headed by appropriate captions.

The order in which these sets of experiments were made was adapted to enable us to distinguish the effect of practice from that of the running start. The average extensor time without a running start was found to be 116.1σ. Although the subjects had been allowed three series of extensor and flexor movements each, by way of practice, it is to be presumed that the effect of practice would continue to make itself felt throughout this first set of experiments, and, indeed, to some extent, through the other sets. The average extensor time for all subjects in the second set with a running start of 3 cm. is 85.8σ, a difference of 30.3σ apparently in favor of the running start. This difference, however, may be due in part or in toto to the effect of practice. When we consider next the average extensor time with a running start of 7.5 cm., that is 89σ, we find a difference of 27σ in favor of the longer running start in comparison with the average time without a running start, but a difference of 3.2σ in favor of the shorter running start, 3 cm., in comparison with the longer running start, 7.5 cm. We must conclude from these values that the difference between the values with 3 cm. and 7.5 cm. start is due not to practice but to the running start. Practice and a running start have produced a low value for 3 cm., but the shorter running start is favored over the longer running start despite the greater practice had in the latter set of experiments. The propriety of this analysis receives further justification on considering the values of the fourth and fifth sets, namely, 97.9σ with a running start of 0.5 cm., and 88.6σ with a running start of 1 cm. Of all the experi-

ments with running start those with 3 cm. were made with the least practice. Despite this fact the average value is the smallest. The average value with a running start of 0.5 cm. is the largest of those with the running start. It would appear from these results that as we increase the running start from 0 to 3 cm. we reduce the rate of movement, and this reduction is of such an amount as to obscure the expected effects of practice. As we pass from a running start of 3 cm. to the longer running start of 7.5 cm. we appear to increase the time of movement, and this despite the fact that practice would lead us to look for a reduction in the average time of movement.

That a running start should reduce the average rate of movement is to be expected. To enter into the explanation of the cause of this reduction is hardly necessary. It is a question of some uncertainty whether the greatest amount of reduction due to the running start is to be expected at the very beginning of the running start and therefore to show most with running starts of very small extent or whether the decrease is due to the getting up of speed which may be supposed to increase proportionately with the extent of the start. My results for extensor movements show the greatest reduction with the smallest running start in comparison with the movement without a running start. I am not permitted to draw any conclusions from this fact at this place owing to the experiments with running starts having been performed late in the investigation and it being impossible to distinguish the effect of this running start from that of practice.

If the reduction in rate of movement is proportional to the extent of the running start we may be surprised at the increased time of movement with a start of 7.5 cm. over the time of those having a 3 cm. start. The difference between these values, as we have said above, represents a true difference between the running starts. The cause for this difference is to be sought in an examination of the results of the individual subjects.

The course of the results for flexor movements is practically the same as that for extensors. The average time of all the subjects without a running start in flexor movements is 102.4σ. This time reduces to 88.1σ with a running start of 0.5 cm., to 78.1σ with a running start of 1 cm., to 74.6σ with a running start of 3 cm., and increases to 76.8σ with a running start of 7.5 cm.

The results of the individual subjects do not in every case conform to the course of those of the averages of all the subjects. It is not to be expected that practice would operate on all the subjects alike, and we may therefore expect when we compare 3 cm. with 0.5 cm. that we will not find in every case the same decrease as we proceed to the longer start. Every

subject shows a considerable decrease in average time with 0.5 cm. from the values obtained without a running start, and a smaller decrease when the running start is increased to 1 cm. This is true of both extensor and flexor movements. But when we increase the start to 3 cm. subject S. shows a considerable increase in both extension (69.8σ to 81.6σ) and in flexion (60.1σ to 70.7σ) and H. shows an increase in flexion (79.2σ to 86.1σ). The other seven values conform to the average result. When we compare the individual results with the running start of 3 cm. and 7.5 cm., we find a decrease in the time of movement for S. in extension (81.6σ to 67.1σ) and flexion (70.7σ to 57.8σ), and for T. in extension (73.8σ to 72.5σ). The other seven values for the longer running start conform to the average result, though the values with 3 cm. and 7.5 cm. for the flexor movements of subject T. are practically the same. S. and T. have a long reach, H., B., and M. have a short reach. Indeed the practical conditions of the experiments showed a stretch of 50 cm. plus a running start of 7.5 cm., to be too long for these three subjects and for this reason I reduced my extent of recorded movement to 35 cm. in a subsequent group of experiments. I believe, therefore, that the increased average time with a running start of 7.5 cm. is due to the diminished rates at the end of the movements owing to the short reach of three of my subjects. So far as my results show at this point the effect of a running start is always to reduce the time of movement, and up to and including a start of 3 cm. it is approximately proportional to the length of start.

At the conclusion of these five sets of experiments. a sixth set *without running start* was made upon my three most practiced subjects S., H., and B. The results of this set gave me standard values for the purpose of comparing effects of running starts after practice has been eliminated. Sixty experiments or three series were made on each subject with both extensor and flexor movements. For the purpose of comparing the averages of these subjects without a running start after practice with their averages with a running start I show in Table 2 the results of the sixth set of experiments with these subjects in the column under the caption "With practice." The other values in this table I have taken directly from Table 1. From Table 2 it will be seen that the average extensor time for the three subjects, without a running start and without practice, is 120.5σ; after practice it is 101.5σ. The average time of these subjects in Ex. with a running start of 0.5 cm, is 91.1σ, with a running start of 1 cm. it is 87.6σ, with a running start of 3 cm. it is 87.1σ, and with a running start of 7.5 cm. it is 86.1σ. We see from these results that the great difference between the movement without a running start and with the smallest run-

TABLE II.

		Time.						Excess of Ex. over Flex.					
		Without Practice.	With Practice.					Without Practice.	With Practice.				
Subj.	Mov't	0	0	0.5	1	3	7.5	0	0	0.5	1	3	7.5
S.	Ex.	83.2	77.0	71.5	69.8	81.6	67.1	4.9	0.4	7.7	9.7	10.9	9.3
	Flex.	78.3	76.6	63.8	60.1	70.7	57.8						
H.	Ex.	122.6	96.8	89.7	83.9	80.7	91.4	18.2	3.4	-9.8	4.7	-5.4	2.2
	Flex.	104.4	93.4	99.5	79.2	86.1	89.2						
B.	Ex.	155.7	130.8	112.2	109.3	99.1	99.7	25.2	28.5	21.5	15.6	18.0	14.2
	Flex.	130.5	102.3	90.7	93.7	81.1	85.5						
Av.	Ex.	120.5	101.5	91.1	87.6	87.1	86.1	16.1	10.8	6.5	10.0	7.8	8.6
	Flex.	104.4	90.7	84.6	77.6	79.3	77.5						

Average times in sigma and excess of extensor over flexor values. Taken directly from Table I. excepting the 0 column "with practice" which are the results of the sixth set of experiments and show the effect of practice upon the time of movement without a running start and the approximation (Subjects S. and H.) of extensor and flexor times as a result of practice.

ning start is not entirely due to practice. The difference is 10.4σ, a further decrease due to doubling the running start is 3.5σ, and a tripling of the running start decreases the average time only 0.5σ. With flexor movements this decisive reduction in the time with the smallest running start is not so apparent. The average time without a running start and without practice is 104.4σ, and with practice it is 90.7σ. This time is reduced when a running start of 0.5 cm. is given to 84.6σ; a reduction of 6.1σ. When the running start is doubled to 1 cm. the time is reduced to 77.6σ a reduction of 7σ. When the running start is increased to 3 cm. the time increases to 79.3σ. Conformity with the rest of our results leads us to expect a decrease in time where we find this increase. This discrepancy is really due to the diminished value, 77.6σ, when the running start is 1 cm. The reduction in the average is contributed by one subject, H., who has the value 79.2σ as the average time with 1 cm. This is far below what we should expect from his other results. I can in no way account for the short times which he gives for the running start of 1 cm. If we exclude this result from the average, thereby increasing the time of flexion with 1 cm., we find that the course of the reduction in movement with flexion corresponds to that with extension, namely, the greatest reduction in time is found with the smallest running start of 0.5 cm., a reduction next in amount with 1 cm. and a further small re-

duction with 3 cm. It would appear, therefore, from these results that the greatest reduction in time is made by the smallest running starts 0.5 cm. and 1 cm. Beyond this extent of running start the times appear to reduce slowly. It is probably fair to conclude, when different subjects traverse a stretch of 50 cm. at a maximal rate of speed, that relatively the greatest loss of time occurs within the first half centimeter of the stretch, certainly within the first centimeter. It is likely that a very considerable part of the recorded time is involved in the actual start of the movement. The elimination of the actual start disposes of a great part of the difference between the rates of movements for different subjects. It should also be considered in this connection that the experiments designated as "*without running start*" were actually made with a start of 1 mm., the distance through which the starting post moved before electrical contact was made and the chronoscope began to record. As we perhaps have a reason to expect from the analysis of the production of voluntary movements the start of the movement is a critical point, not only during the course of preparation preceding the actual start, but for the fraction of a second after the movement is actually begun.

The values in Table 2 under the caption "Excess of Ex. over Flex." show the effect of practice upon the difference between the time of extensor and flexor movements. This effect is especially noticeable in the two columns under "0," the first of which contains values based upon the results of the first set of experiments without a running start and without previous practice, and the second contains values based upon the results of the sixth set which was made without a running start but with the advantage of practice in all the preceding sets of experiments. An inspection of the total averages of these two columns shows that the excess of extensor movement time over flexor movement time has been reduced from 16.1σ to 10.8σ. In the case of S. the reduction is from 4.9σ to 0.4σ; in the case of H. from 18.2σ to 3.4σ. As to B., however, the result is quite different: the excess has increased from 25.2σ to 28.5σ. In other words for the two subjects S. and H., extensor and flexor movement times have approximated each other. This approximation is effected by the greater decrease in extensor than in flexor movement times. This result is shown in Table III in which I have isolated the extensor and flexor movement times for S., H., and B., with no running start, without practice and with practice respectively, and have shown in the column on the right the decrease in extensor and flexor times respectively for each subject. Extensor times for S. decreased 6.25σ and flexor times only 1.7σ; for H. extensor times decreased 25.80 and flexor times only 11.0σ. In the case of B., on the

TABLE III.

Subject.	Movement.	Without Practice. σ	With Practice. σ	Decrease.
S.	Ex.	83.2	77.0	6.25
	Flex.	78.3	76.6	1.7
H.	Ex.	122.6	96.8	25.8
	Flex.	104.4	93.4	11.0
B.	Ex.	155.7	130.8	24.9
	Flex.	130.5	102.3	28.2

other hand, the greater decrease was in flexor times; 28.2σ against 24.9σ. This probably indicates that in the case of subjects S. and H. the extensor muscles of the arm were under less perfect control than the flexors when the experiments of this investigation began.

Granting that this be true, we must not suppose, in analogy with so many processes of learning, that there is, at the outset, a relative imperfection in the connection of the nervous tracts leading from the cortical centres to the root cells of the motor nerves for the extensor muscles of the arm. This would be the argument in a study of reaction-times but in the present case it may or may not be true. It is with the time required for movement and not with the motor impulse from the cortex that we are concerned. The core of the present problem is in the education or training of the muscle itself and probably also in the training of afferent tracts from the muscle to the cord and the corresponding efferent tracts. For if we estimate the rate of the nervous impulse between the extensor of the arm and the brachial region in the cord at 27 M. per sec. we find that in 40σ, which is about one-half of the duration of an extensor movement over 50 cm., the nervous impulse can travel over a little more than one meter. But this is a greater distance than that between the extensor of the arm and the brachial region. It would seem, therefore, that in the course of a movement occupying 85σ or 90σ, and probably in movements of shorter duration, there is time for a sensory impulse from the muscle to reach the cord, and for a motor impulse to return in time to re-enforce the primary impulse which initiated the movement. The more quickly after the beginning of the movement this re-enforcement occurs, if it occur at all, the greater will be the acceleration of the movement within the 50 cm. course and consequently the shorter the time required to make the desired movement. Camerer (2 : 25) showed that in movements not of the maximal rate, the instant of greatest velocity in the extensor movement occurs nearer the end of the course than in

the flexor movement. It is possible that the same would be found true of movements of intended maximal rate and 50 cm. in extent. It might even be found that the moment of maximal velocity is subsequent to the moment at which the 50 cm. limit is passed. In this case, obviously, any means that would hasten the instant of maximal velocity so as to bring it within the time required in covering the course of 50 cm., or whatever it may be, would have the effect of increasing the rate of movement over the whole course. Whether any such process has occurred in these experiments, there is no means of knowing since my apparatus is not adapted for obtaining any information on this point. It is necessary to have the variations in rate from the beginning to the end of each separate movement throughout a long course of training before any conclusion can be offered in this matter.

I have already called attention to the fact that the average mean variation of all subjects for extensor movements is less than for flexor movements, despite the fact that the extensor movements are of longer duration than the flexor movements. The course of the mean variation compared with the average times presents little of interest, the mean variation varying with the values themselves. It is perhaps worth calling attention to the small average mean variation, 1.1σ of Subject T. in flexion with 7.5 cm. start (see Table I). Another subject, S., has a variation with the same start of but 1.7σ. These variations represent a remarkable constancy in the rate of movement. The relatively large variations of the time values of B. and M. for 7.5 cm. start indicate perhaps a greater unsteadiness owing to the short reach of each subject. The total averages of the mean variations follow the same general course as the total averages of the time values. There is a sharp decrease in the averages of the 0.5 cm. column, as compared with the averages of the 0 column; from 8.9σ to 4.2σ and from 10.6σ to 4σ respectively, with differences of 4.7σ and 6.6σ for extension and flexion respectively. There is a slight increase of the average for flexion with a start of 1 cm. over that with a start of 0.5 cm.; 4.3σ compared with 4σ. With this exception there is an almost uniform decrease in the average values until the 7.5 cm. start is reached where a slight rise occurs in conformity with the general result of the time of movement. It is perhaps worthy of notice that this slight irregularity in the course of the average variations is due to the large mean variations of B. in both extensor and flexor movements and of H. in flexor movements. Consequently the same disturbance occurs in the averages of the three most practiced subjects, S., H., and B., given at the foot of Table I.

During an extended course of experiments it is to be ex-

pected that diurnal variations in the time of movement, resulting from the inconstant physical condition of the subjects will occur.

TABLE IV.

Subj.	Movt.	0	0.5	1	3	7.5
S	Ex.	3.5	4.3	4.7	2.7	1.0
	Flex.	3.4	5.0	5.8	3.5	1.1
H	Ex.	5.1	4.3	4.1	4.9	5.0
	Flex.	5.5	5.2	4.5	2.9	4.2
B	Ex.	3.7	3.1	5.6	2.5	2.8
	Flex.	5.1	4.8	4.1	3.1	3.0
Total Av. Daily Var.	Ex.	4.1	3.9	4.8	3.4	2.9
	Flex.	4.6	5.0	4.8	3.2	2.8

In these experiments, however, the variations of this kind were slight and there is no evidence that they have affected the general results. The values represented in Table IV are those of the mean variations of the daily mean variations of the time of movement from their average. They pertain to three subjects, S., H. and B. The results obtained from subjects T. and M. are excluded from this table because their experiments under each condition of running start, were made in one day. The values in the column headed "o." are the mean variations of ten daily variations from their average. They are the results of all experiments made with no running start, within a period of four weeks at the beginning of the year 1904-1905. The values represented in the remaining columns are in each case the mean variations from the average of six mean daily variations and the experiments on which each column is based covered a period of two weeks. Below, and opposite the caption "Total Av. daily Var." are the averages of the diurnal variations of all subjects.

The result is very satisfactory. The average daily variation of extensor movements ranges from 2.9σ to 4.8σ, and of flexor movements from 2.8σ to 5.0σ. Experience has led us to expect just such variations as these from fairly practiced subjects even in the course of a single series of experiments. The statement that diurnal variations do not affect the final results of these experiments seems therefore to be justified. Notwithstanding this I decided to conduct a series of tests of the maximal rate of movement under all the conditions of running start which had been employed in the preceding experiments, but from which the possibility of diurnal variations in rate should be eliminated,

and from the beginning to the end of which each subject should be in an approximately uniform condition as regards practice. It was necessary accordingly to obtain from each subject in a single experimental period a record of his best effort under all the conditions of running start. To make this practicable without fatiguing the subjects I employed a series of only ten flexor and ten extensor movements. The course over which the time of movement was to be recorded was reduced from 50 cm. to 35 cm. in order to bring it easily within the reach of my shortest armed subjects. The successive series of experiments were made in the order of the increasing running start. The first series was with no running start, the second with a start of 0.25 cm., which was not employed in the former experiments, the third with 0.5 cm. start, and the fourth, fifth and sixth series were made with a start of 1 cm., 3 cm., and 7.5 cm. respectively. Five subjects took part in these experiments, of whom S., H., and B. were practiced in the experiments which have just been reported. G. and E. were unpracticed subjects. The results of these experiments are tabulated in Table V. Each value in this table represents an average of only ten experiments; a single series. In the third column from the left of the table under the caption "0." are the averages of the ten extensor and ten flexor movements without a running start made by each of the five subjects who are designated by initial in the first column. The averages of the movement times with running starts in succeeding series are tabulated in the same manner under the appropriate captions and the corresponding mean variations are set down in the middle group of columns from left to right under the caption "Mean Variations." On the right are the differences between the times of flexor and extensor movements. At the foot of the tables are the total averages of the averages of extensor and flexor movements of all subjects and also the separate total averages of the values for three practiced subjects, S., H., and B.

By referring to the total averages in the tables it will be seen that the average of all subjects' average extensor movement time is 78.4σ, while that of the flexor movement time is 69σ. The averages of the extensor and flexor values in the column under the caption 0.25 cm. are respectively 77.5σ and 68.2σ; a reduction of only 0.9σ and 0.8σ respectively from the total averages of the first column. The averages for extensor and flexor movements respectively in the columns headed by 0.5 cm., are 77σ and 66.8σ; a further reduction of 0.5σ and 1.4σ. From this point the decrease of the total averages is more rapid; from 77σ to 72.7σ, and from 66.8σ to 58.8σ for extension and flexion respectively, with a start of 1 cm. With a start of 3 cm. the averages descend to 67.2σ and 55.3σ; an ad-

TABLE V.

		Time.						Mean Variation.						Excess of Ex. over Flex.					
Subj.	Mov't	0	0.25	0.5	1	3	7.5	0	0.25	0.5	1	3	7.5	0	0.25	0.5	1	3	7.5
S.	Ex.	62.4	61.8	63.2	57.6	53.8	51.3	3.7	3.9	1.8	2.4	3.6	2.2	2.5	4.6	9.2	8.2	7.8	9.2
	Flex.	59.9	57.2	54.0	49.4	46.0	42.1	3.1	2.9	1.4	1.5	1.0	1.2						
H.	Ex.	89.1	89.0	88.1	81.8	76.0	72.4	4.1	3.9	3.3	2.9	2.2	2.7	8.8	7.6	8.9	11.7	6.7	8.1
	Flex.	80.3	81.4	79.2	70.1	69.3	64.3	5.6	5.9	5.2	3.0	2.3	2.4						
B.	Ex.	98.5	97.9	96.1	86.7	80.4	72.4	5.5	3.2	2.4	2.2	2.1	3.1	21.5	19.7	20.5	20.0	13.1	12.2
	Flex.	77.0	76.2	75.6	66.7	59.7	50.8	2.1	3.4	4.1	5.5	1.7	2.2						
G.	Ex.	67.4	64.9	65.0	64.5	59.7	50.8	2.1	3.4	4.1	5.5	1.7	2.2	2.0	1.1	1.9	14.7	14.6	9.4
	Flex.	65.4	63.8	63.1	49.8	45.1	41.4	2.7	2.6	2.3	1.4	2.1	2.2						
E.	Ex.	74.8	74.0	73.8	73.0	66.1	63.2	4.8	4.7	3.9	1.8	1.7	3.8	7.1	13.1	11.7	14.6	10.8	7.7
	Flex.	67.7	62.7	62.1	58.4	56.3	55.5	6.9	5.6	3.0	1.9	2.7	1.9						
Total Avs.	Ex.	78.4	77.5	77.0	72.7	67.2	62.0	4.0	3.8	3.1	2.9	2.2	2.8	9.8	9.2	10.4	13.8	10.6	9.3
	Flex.	69.0	68.2	66.8	58.8	55.3	52.3	4.2	4.2	3.3	2.5	2.0	1.9						
Avs. of S. H. B.	Ex.	83.3	82.9	82.4	75.3	70.1	65.3	4.4	3.6	2.5	2.5	2.6	2.6	10.9	10.6	12.8	13.3	9.2	9.8
	Flex.	72.4	71.6	69.6	63.1	58.3	54.9	3.8	4.3	3.8	3.0	1.8	1.8						

Average times in sigma and average mean variations of extensor and flexor movements over 35 cm. without a running start, and five extents of running start. Each value is the average of ten. The table gives also the excess of extensor over flexor values.

ditional decrease of 5.5σ and 3.5σ respectively for extensor and flexor movements. Finally, with a start of 7.5 cm. there is a further decrease of 5.2σ and 3σ for extensor and flexor movements respectively, *i. e.*, from 67.2σ to 62σ, and from 55.3σ to 52.3σ. These differences indicate a very slight decrease in the time of movement with a start of even 0.5 cm. and a rapid and almost uniform decrease up to and including the longest running start, 7.5 cm. An inspection of the individual values in the table shows no series of results the course of which does not run parallel with that of the final averages.

The total averages of the mean variations follow approximately the same course as the averages of the times movement. There is, however, one discordant result, namely, the average mean variation of extensor movements, 2.8σ, in the column under the caption 7.5 cm. This result is 0.6σ higher than the total average of mean variations in extension in the column headed 3 cm. This disturbance of the uniformity of the final result is introduced by one of the unpracticed subjects, E., whose mean variation in extensor movements with a start of 7.5 cm. is 3.8σ against 1.7σ with a start of 3 cm. The average mean variations of the three most practiced subjects, S., H., and B., are still less in accord with the total averages of the time of movement, due chiefly to subject B.'s large variations

in flexor movements with a start of 0.5 cm. and 1 cm., and to the want of uniformity in S.'s mean variations in both extensor and flexor movements. The total average movement times of these three subjects, while higher than the total average of all subjects, conforms to the general result.

The experiments of the second main division of this investigation were undertaken for the purpose of finding the effect of back pressure and the time during which it is exerted, upon the time of movement over a course of 50 cm. with no running start.

For the purpose of the first set of these experiments, namely, to find the effect of "back pressure" alone upon the time of movement, the instrument illustrated in Figs. 3 and 4 was brought into use but only the marker "*w*," Fig. 3, was employed on the kymograph. The data for the following results were obtained from eight subjects, He., Ma., E., St., W., J., Mc., and V. He., E., St., and V., were graduate students in psychology, Ma., was a visitor at the laboratory, and the others, W., J., and Mc., were graduate students in chemistry and biology. All of these subjects were unpracticed excepting E., who had had practice in the one series of experiments with a 35 cm. course under the various conditions of running start. It is desirable to employ practiced subjects in these experiments provided they are ignorant of the purpose of the investigation. All of my practiced subjects, however, had knowledge of the object of the experiments, and it was feared that this would affect the results which might be obtained from them in this part of the investigation. They were therefore excluded, and the data which I shall present in the following pages is collected only from unpracticed subjects.

Three or four preliminary trials were made with each subject in order to make him familiar with the apparatus and the signals. The amount of back pressure that each subject would probably exert was determined in these preliminary trials, and the tension of the spring in the balance "*F*" (see Fig. 2) was adjusted accordingly. It was apparent, even from these preliminary trials, that there would be large individual variations in the amount of back pressure. If the tension of the spring in the balance "*F*" were constant there would, in some cases, be a large, and in other cases a slight displacement of the lever "*C*." But in order to eliminate as far as possible, difference in the extent of backward start as a factor in the results, the tension of the spring at the beginning of each series was adapted as nearly as could be to the probable amount of back pressure that would be exerted by each subject as indicated in the preliminary trials. Some subjects therefore began the push-back against a heavier initial dead weight than others. This

inequality in conditions, it seems to me, is of little if any consequence in these experiments inasmuch as the tension of the spring was constant for each subject. The tension of the spring was usually set at 100 g. though in some cases it was as low as 0., and in others at intermediate points, determined in each case by preliminary experiment.

After a series of ten extensor and ten flexor movements the operator has the chronoscope readings and also the tracings of the marker "*w*," Fig. 3, upon the smoked surface of the kymograph. The latter are measured and the value of each excursion of the marker "*w*" is computed in grams. A single example will illustrate the method. Suppose the tension of the spring in the balance "*F*" is such that the indicator points to 100 g. Now if the lever "*C*" is pushed back until the indicator on the balance points to 200 g., the marker "*w*" has made an excursion of 8 mm. on the kymograph. The subject in such a case has overcome the initial 100 g., and has added another 100 g. to the reading on the balance. But he has been pushing at "*G*" against a lever of the third order in which the length of the whole lever (50 cm.) is one and one-half times that of the long arm (33.3 cm.). Hence in the above case the amount of back pressure is equal to 1.5 (100 g. + 100 g.) = 300 g. That is with the tension of the spring at 100 g. an excursion of 8 mm. on the kymograph represents a pressure of 300 g. All computations of back pressure were made in a similar manner.

The ten chronoscope records and the ten records of back pressure were averaged to obtain the values which are set down in Table VI. In this table in the column under the caption "Subj." are the initials of the eight subjects who aided in these experiments, and on the right of this the two columns under the caption "Pressure" contain the average back pressure in

TABLE VI.

	Pressure.		Time.	
Subject.	Ex.	Flex.	Ex.	Flex.
He.	416	650	92.7	87.3
J.	350	475	127.3	110.1
Mi.	280	435	120.2	100.3
W.	240	384	115.2	101.4
Ma.	233	420	106.7	80.5
V.	220	285	144.7	120.1
E.	210	260	153.3	115.3
St.	206	363	110.6	90.4
Av.	269.3	409.06	121.3	100.7

grams exerted by each subject in extensor and flexor movements respectively. The last two columns on the right contain the averages of the times of these movements.

In every case a longer time is required for extensor than for flexor movements and the back pressure in extensor movements is always less than that in flexor movements. In the case of He., for example, the time for extension is 92.7σ, and the back pressure is 416 g. The time for flexion, on the other hand, is 87.3σ, and the back pressure is 650 g. Taking these eight subjects together the average time of extensor movements, shown at the foot of Table VI, is 121.3σ; of flexor movements, 100.7σ. The corresponding averages of back pressure are 269.3 g. and 409.06 g. respectively. That is, while the average time of flexion is 20.6σ shorter than that of extension, the average back pressure in flexion is 139.76 g. higher than in extension. A study of the individual results showed, however, that a single very rapid movement is not invariably preceded by a high degree of back pressure. Moreover, a very rapid movement is sometimes preceded by a less intense pressure than a slower movement. The averages in Table VI show further that a subject whose time is short does not invariably exert a high degree of back pressure. Ma., *e. g.*, whose extension time is next to the shortest gives a low back pressure in extension; only 233 g. and though his flexion time is shortest on the list, namely 80.5σ, there are three (He., J., and Mi.), whose back pressure in flexor movements is greater than his.

If the amount of initial back pressure were an important factor in determining the time of the subsequent movement we should find that a large difference between the times of flexor and extensor movements occurs together with a large difference between the back pressure exerted in preparation for the same movements. In an attempt to find such a correspondence in the case of the eight subjects of these experiments I have taken the differences between the back pressure values and the time values in Table VI and from these differences I have constructed Table VII. The pressure differences for each subject in the "Pressure" column are arranged in order from the largest to the smallest. In the "Time" column on the

TABLE VII.

Subject.	Pressure.	Time.	Subject.	Pressure.	Time.
1 He.	234. g.	5.4 (8)	5 W.	144.	13.8 (7)
2 Ma.	187.	26.2 (2)	6 J.	125.	17.2 (6)
3 S.	157.	20.2 (4)	7 V.	65.	24.6 (3)
4 Mi.	155.	19.9 (5)	8 E.	50.	38. (1)

right are the differences between each subject's times for flexion and extension. The figures in parentheses on the right of this column designate the place which each value would occupy if placed in order from the largest to the smallest. The subject "*He.*" who has the largest difference in pressure, 234.5 g., has the smallest difference in time, 5.4σ. The subject *E.* who has the smallest difference in pressure, 50 g., has the largest difference in time, 38σ. Another subject, V., who has the next smallest difference in pressure, 65 g., has a large difference in time, 24.6σ. If we exclude these three subjects from consideration, we find with the other five subjects that the excess of pressure with the flexor movement is correlated with a corresponding reduction in the time of flexor movements, although the order of subjects *W.* and *J.* for time of movement is the reverse of that for pressure, the difference in neither case, however, being large. The evidence presented in this table, not very strong to be sure, appears to warrant the conclusion that on the average the more rapid movements are preceded by a higher degree of back pressure and the slower movements by lower pressure. My results show unequivocally that greater back pressure occurs in preparation for flexor movements. This means, of course, that there is a more intense antagonistic contraction of the extensor than the flexor muscles. Perhaps in the motor area of the cortex dispersion of excitation occurs more readily in the direction of the centre of the extensor than of the flexor muscles. This would not necessarily contradict the facts as they appear in spastic paralysis, in which disorder there is a continuous strong contracture of the flexor muscles. In these cases the cortical excitation has had time to overcome the greater resistance toward the flexor centres—granting that there is a greater resistance in this direction—whereas in these experiments the cortical excitation and its dispersion cover a period of only several hundredths of a second at most, and the resistance toward the flexor centres can probably be only partially overcome in so brief a time.

The results of the experiments which had to do with the final purpose of this investigation, namely, to find the effect of the time during which back pressure is exerted upon the time of movement, are necessarily based upon meagre data owing to the tedious nature of the experiments. In addition to the marker "*w*," Fig. 3, which traces the pressure curve upon the kymograph, we require the electro-magnetic marker "*N*" which is actuated by a current passing through the posts "*k*" and "*n*," and marks on the kymograph the point in the curve traced by the marker "*w*" at which back pressure ceases and the movement is begun. The tuning fork "*M*" traces the time line by which the duration of back pressure is determined.

The kymograph was therefore necessarily run at such high speed that though it carried fully three meters of paper it was a matter of great difficulty to get more than 8 or 10 records upon a single sheet.

The five subjects of these experiments were graduate students in chemistry and biology. All were unpracticed excepting Wi., who made but one series of ten flexor and ten extensor movements in the preceding set which had to do with the effect of back pressure upon the time of movement, and all were ignorant of the object of the experiments.

The results of these experiments are embodied in Table VIII, in which are shown the time of movement, the back pressure measured in grams, and the duration of back pressure measured in fractions of a second for each subject in extension and flexion. Each value represents an average of four or five.

In the case of Wi. the average time of the extensor movements, 106.3σ, is shorter than that of the flexor movements, 149.6σ, and the shorter time of back pressure, 0.08 sec., precedes the shorter movement; extension 106.3σ. In three cases out of the five, O. S., and Mc., in flexion, and Ha. in extension, the longer average duration of back pressure occurs with the shorter time of movement.

TABLE VIII.

	Extension.			Flexion.		
Subj.	Time.	Back Pressure.	Time of Pressure.	Time.	Back Pressure.	Time of Pressure.
Wi.	106.3	168.75	0.08	149.6	187.5	0.1
O. S.	97.0	375.0	0.44	74.0	431.25	0.78
Mc.	89.0	800.0	0.53	74.0	950.0	1.06
P.	82.7	60.0	0.275	68.3	483.0	0.23
Ha.	96.97	65.7	0.626	100.6	46.65	0.52
Av.	94.39	293.89	0.39	93.3	417.68	0.54

That is with subject O. S., the duration of back pressure in the shorter, or flexor movements, is 0.78 sec. as compared with 0.44 sec. in the longer or extensor movements. With Mc. it is 1.06 sec. with the shorter and 0.53 sec. in the longer time of movement, and with Ha. it is 0.626 sec. in the shorter and 0.52 sec. in the longer time of movement. On the other hand, in the results obtained from Wi. and from P., the longer duration of back pressure occurs with the longer time of movement. In the first case it is 0.1 sec. with the longer movement compared with 0.08 sec. with the shorter movement, and in the second, 0.275 sec. with the longer and 0.23 sec. with the shorter. The

averages of the values in Table VIII show that on the whole the longer duration of back pressure (0.54 sec.) occurs with the briefer or flexor movement (93.3σ) but the evidence of the individual results is not decisive. It is worthy of notice, however, that the results obtained from each of these subjects, excepting Wi., confirms the results of the preceding set of experiments inasmuch as they show that the greater amount of back pressure occurs on the side of the more rapid or flexor movements. For the one exception to this general result I am not able to account.

It is well known that in the education of a boxer the first precaution is to train him out of the habit of "telegraphing," as it is called; or drawing the arm backward in preparation for a stroke. In the light of the experiments discussed in this paper, and of those reported by Woodworth on "The Voluntary Control of the Force of Movement," (9), it seems to me that the boxer's backward start before dealing a blow may, on the whole, aid him in making a quick and forcible stroke. If this is true the only justification for training him out of this behavior lies in the fact that the backward start tells the opponent when and where the expected blow will come. Since the boxer may be trained out of this antagonistic action it seemed probable that my most practiced subjects may, in the course of practice, have trained themselves out of the back pressure preparation for arm movements.

Accordingly the matter was put to trial with S. and T. both of whom knew the purpose of the test. The former acted as my subject in all the experiments of the first division of this investigation; namely, those to determine the effect of the running start upon the time of movement. While T. had considerably less practice in these experiments he was well trained in similar investigations in previous years.

Each subject first submitted to two series of experiments of ten flexor and ten extensor movements each in which the tension of the spring in the balance "*F*," Fig. 2, was reduced to 0. He was urged to make the quickest possible movement while at the same time avoiding back pressure. Following this were two series in which for each subject the tension of the spring was set at 200. In these series the subjects were not requested to avoid back pressure without giving attention to the initial stage of the movement. It is probable that the lack of such instruction, since these series followed immediately after the preceding, suggested the backward push so vividly that there is a greater difference between the back pressures with no tension and those with a tension equivalent to 200 g. than would otherwise appear. The results of these experiments appear in Table IX in which the time of move-

TABLE IX.

		Extension.		Flexion.	
Subj.	Tension of Spring.	Time.	Pressure.	Time.	Pressure.
S.	0	94.5	93.12	86.9	97.5
	200	76.6	946.8	64.9	1336.6
T.	0	80.6	41.25	69.1	226.5
	200	76.3	818.4	65.0	1031.2

ment and back pressure are arranged horizontally in line with the figures which designate the tension of the spring. In every case the greater back pressure is in the flexor movements where also the time is the shorter. When the tension of the spring was 0. and the subjects were asked to avoid back pressure, at the same time making the quickest possible movement, some back pressure was, nevertheless, exerted. In the case of S. it was 93.12 g. and 97.5 g. in extension and flexion respectively. For T. it was 41.25 g. and 226.5 g. respectively. When the tension of the spring was made equivalent to 200 g. and the subjects were not instructed to avoid back pressure but only to make the quickest possible movement, S. considerably reduced his time of movement; namely, 94.5σ to 76.6σ in extensor movements. T.'s time was less reduced; from 80.6σ to 76.3σ in extension and from 69.1σ to 65σ in flexion. When the tension of the spring was made 200 g. and the subjects attended only to the speed of the required movement, S.'s back pressure was increased from 93.12 g. to 946.8 g. in extension, and from 97.5 g. to 1,336.6 g. in flexion, while T. increased his back pressure from 41.25 g. to 818.4 g. and from 226.5 g. to 1,031.2 g. in extension and flexion respectively. These results indicate that these subjects have not in the course of practice been trained out of the backward start or back pressure. They indicate, further, that attention when directed to the beginning of a movement increases its time, for when under the second condition of the experiment, namely, when they were required to attend only to the speed of the movement and not to the behavior at the beginning of the movement, the time of movement is reduced, as pointed out above, from 94.5σ to 76.6σ, and from 80.6σ to 76.3σ in extensor for S. and T. respectively, and in flexor movements from 86.9σ to 64.9σ and from 69.1σ to 65σ.

SUMMARY.

The results of this investigation may be briefly summarized. With but two indecisive exceptions the fourteen subjects of

these experiments are more rapid in flxeor than in extensor movements. But while the maximal flexor rate is the higher it is less constantly maintained than that of extensor movements; *i. e.* the mean variation of the flexor times is higher than that of the extensor times.

The rate increases and the mean variation decreases as the running start is made longer but not beyond a certain maximal start. Among starts of 0.5 cm., 1 cm., 3 cm. and 7.5 cm. that of 3 cm. is most favorable for a rapid movement over a course of 50 cm. The greatest loss in time and the largest variations occur within the first centimeter of the course; perhaps within the first half centimeter.

For some subjects there is, as a result of practice, a greater increase in the rate of extensor than of flexor movements.

The initial backward start or "back pressure" is not a constant factor in determining the rate of movement. The greater amount of "back pressure" almost invariably occurs, on the average, in preparation for flexor, which are the more rapid movements.

The duration of "back pressure," as far as this investigation shows, has no effect upon the rate of movement.

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